Lecture 15:
Toolkit support for Gestural Input Techniques, Handwriting Recognition

05-431/631 Software Structures for User Interfaces (SSUI)

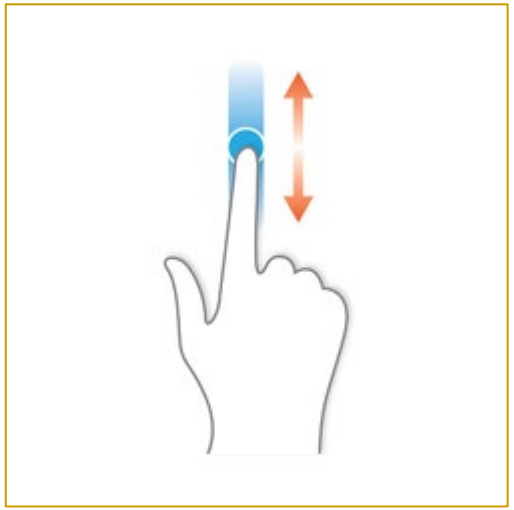
Fall, 2021

Logistics

- Thanks for those who filled out survey
  - Still available: https://www.surveymonkey.com/r/SSUI2021midterm
  - Slides are available in pdf format
  - Will try a different microphone for recordings
  - *Please let us know about what else we can do to be helpful*

What is a "Gesture"

- In HCI, an input to a computer where the *path* or other properties of the input is important to its recognition, not just the end points
  - Regular drag-and-drop just cares about where starts and finishes, so generally does *not* count as a "gesture"
- A recognizer is needed to interpret the path – so it may be interpreted incorrectly
- Can be done with a mouse, a stylus or finger on touchscreen, or hands in the air in front of a camera
- Can be one or multiple fingers; one or multiple strokes
- On Smartphones, call "tap" a "gesture" to distinguish between tap, long-press, flick, drag, etc.
  - Depends on properties of the action or of the *other actions*
    - Location, but also speed, timing, etc.



Advantages of Gesture Recognition

- Very fast to enter
- Single gesture can give both parameters and command
  - E.g., cross out gesture tells both what to do and to what
- Large space of potential gestures
- Can be “natural”
- Can fit in easily with event-based programming
  - Assuming gestures simply invoke a command
- Can be integrated with the toolkit
  - E.g., get events when a gesture starts / finished

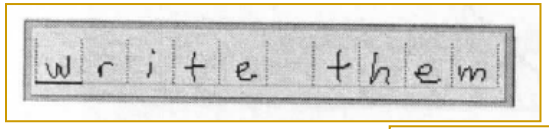
Disadvantages

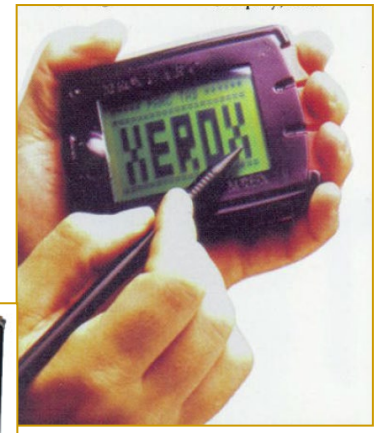
- No affordance – user has to know they can be done
- No in-place information on what they look like
- User may find it hard to remember which gesture does what operation (especially if lots)
- System may recognize them incorrectly
- Often cannot be entered correctly by users with disabilities, etc.
- Can be unnatural if designed poorly
- Hard to provide feedback of what is happening, especially if continuous
- Implementation challenge: creating a good recognizer
- Designer must decide if rotation and size invariant

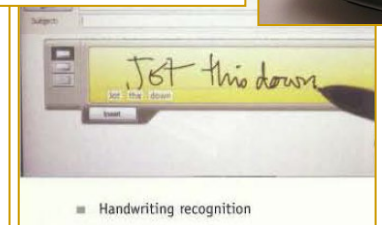
Gestures → Character → Handwriting recognition

- Text entry using hand-printing and hand-writing
  - Rand tablet (1964)
  - PARC Tab QuickWriting (1989)
  - Go PenPoint (1991)
  - Apple Newton (1993)
  - Palm Graffiti (1996)
  - Windows TabletPC (2002)
  - EdgeWrite (2003)

Fig. 1—Complete system in operation







Gestures in 3D

- Gestures for 3D manipulation
  - Mainly pose and path of fingers with dataglov
  - Also elaborate gestures in Teddy
  - May depend on path and timing
  - Wii controller gestures
  - Kinect Body poses

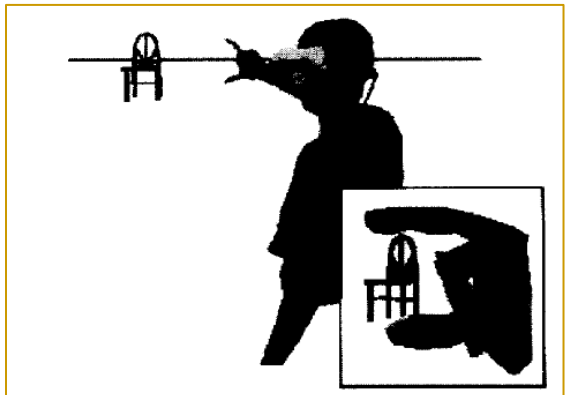


Figure 3: A third person view of the Head Crusher technique. The inset shows the first person view.

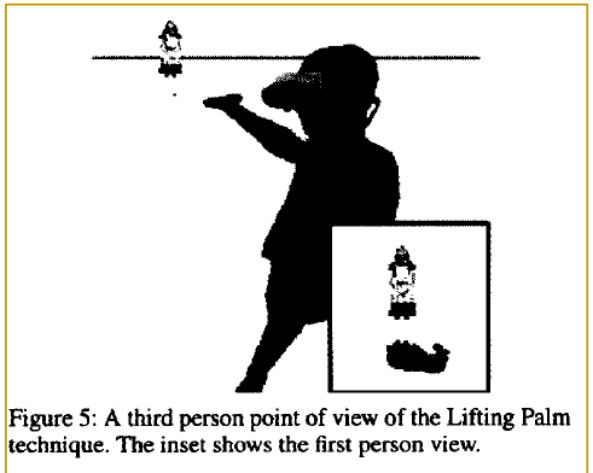
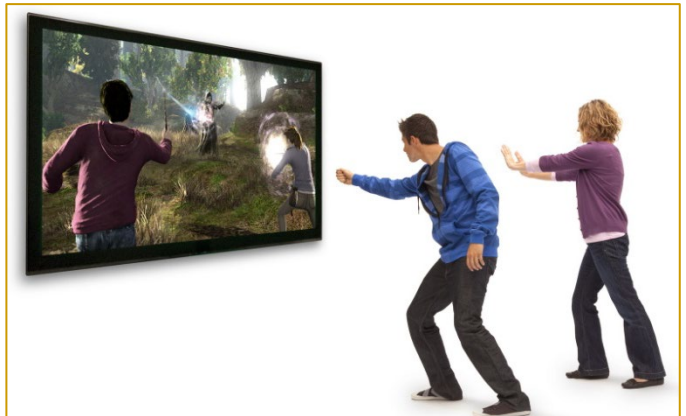


Figure 5: A third person point of view of the Lifting Palm technique. The inset shows the first person view.



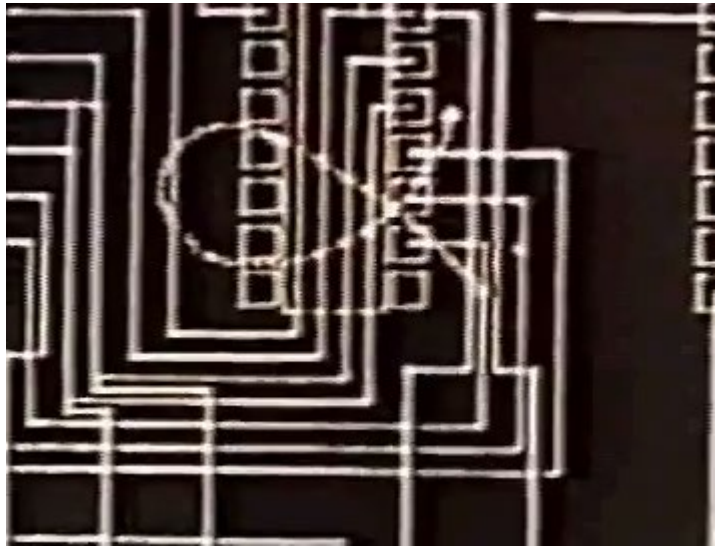
Gestures for Proofreading

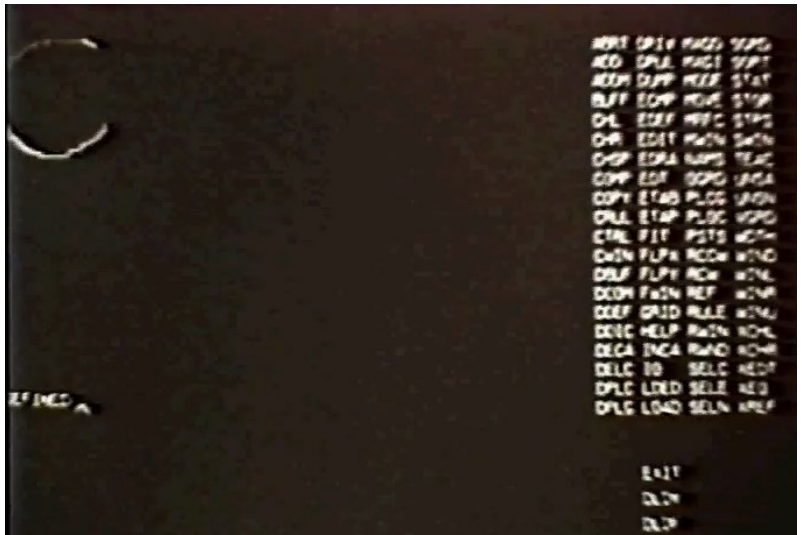
- Well-known proofreading symbols on paper
- Many investigated using these gestures
- COLEMAN, M. L. Text editing on a graphic display device using hand-drawn proofreader's symbols. In *Pertinent Concepts in Computer Graphics, Proceedings of the Second University of Illinois Conference on Computer Graphics*, M. Faiman and j. Nievergelt, Eds. University of Illinois Press, Urbana, Chicago, London, 1969, pp. 283-290.

- RHYNE, J. R., AND WOLF, C. G. *Gestural interfaces for information processing applications*. Tech. Rep. RC12179, IBM T.J. Watson Research Center, Sept. 1986.

Trainable Gesture Recognizer

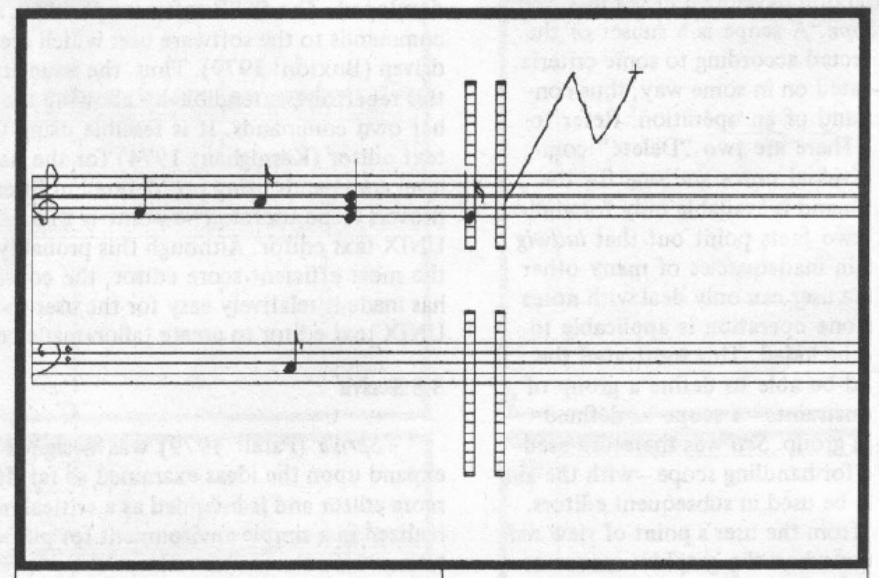
- Applicon (circa 1970). An interactive trainable computer aided circuit design system using hand-drawn shapes to enter data and commands. Applicon. 16 mm film. Video (2:25 min excerpt)
  - From Bill Buxton Lincoln Labs page. See the Wikipedia entry





Early Gesture Recognition

- **Buxton, W., Sniderman, R., Reeves, W., Patel, S. & Baecker, R. (1979).** The Evolution of the SSSP Score Editing Tools. *Computer Music Journal* 3(4), 14-25. [PDF] [video]
- Can draw gestures for the desired notes to enter music
- Start location determines pitch



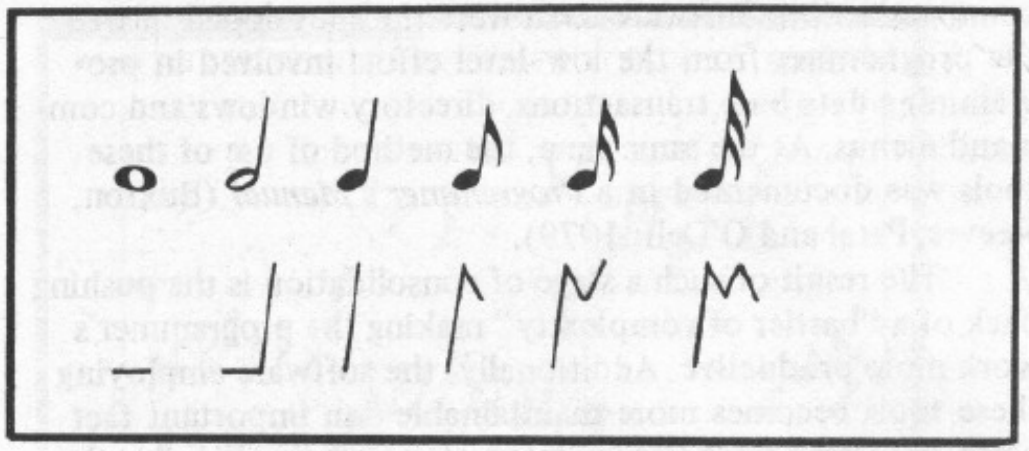


Figure 10. *Char-rec* duration symbols

Early Graphical Editing Gestures

- Buxton, W., Fiume, E., Hill, R., Lee, A. and Woo, C. Continuous Hand-Gesture Driven Input. *Proceedings of Graphics Interface '83,* Edmonton, May 1983, 191-195. http://billbuxton.com/gesture83.html [video]
- Gestures for move and copy
- Copy is same except make a "C" gesture along the path after circling and before moving

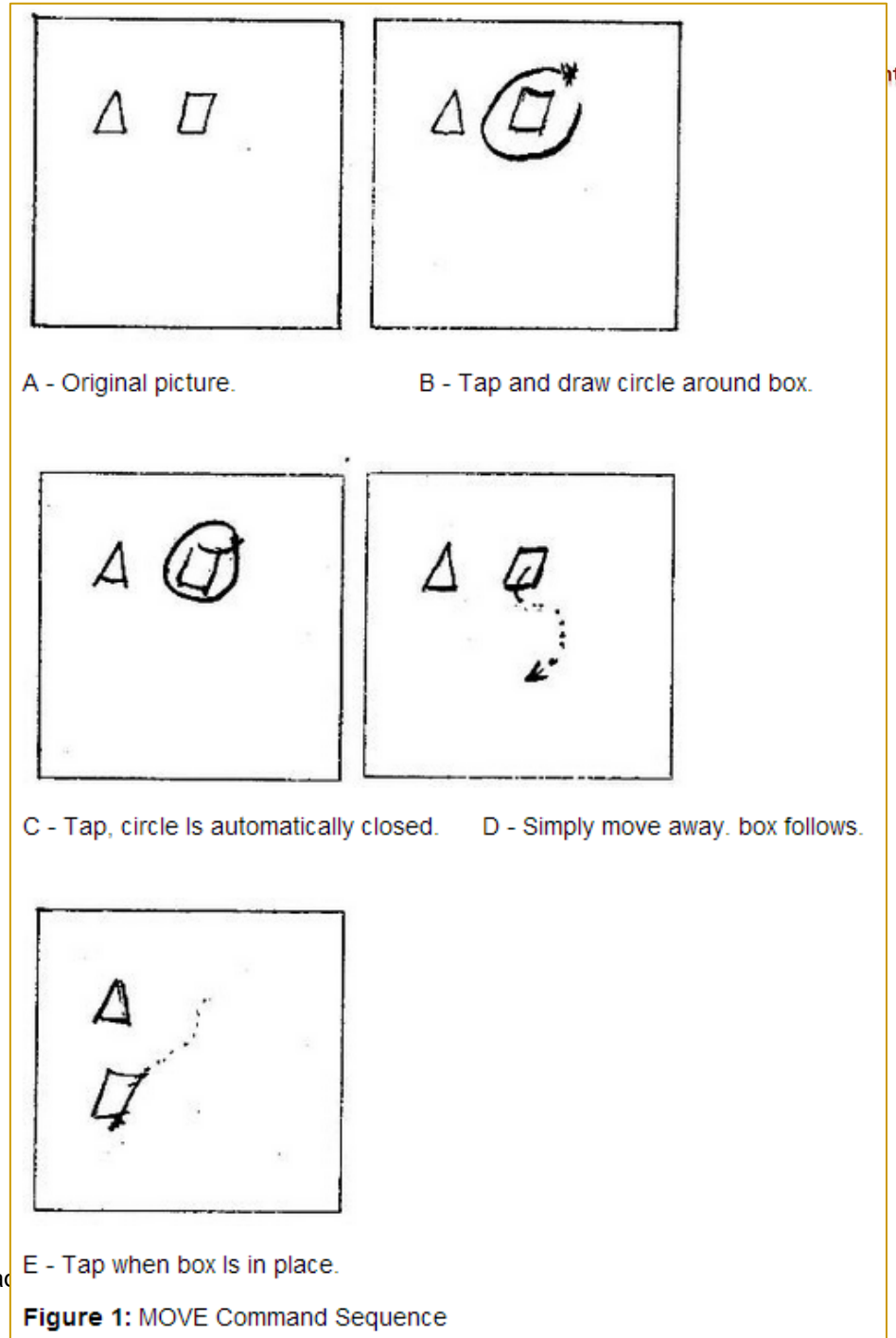
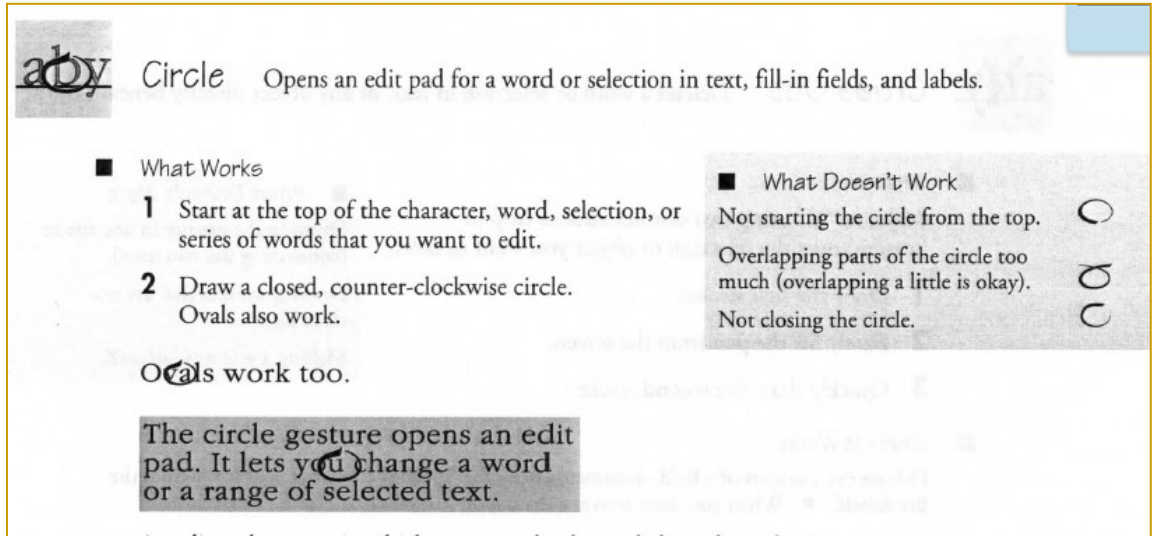
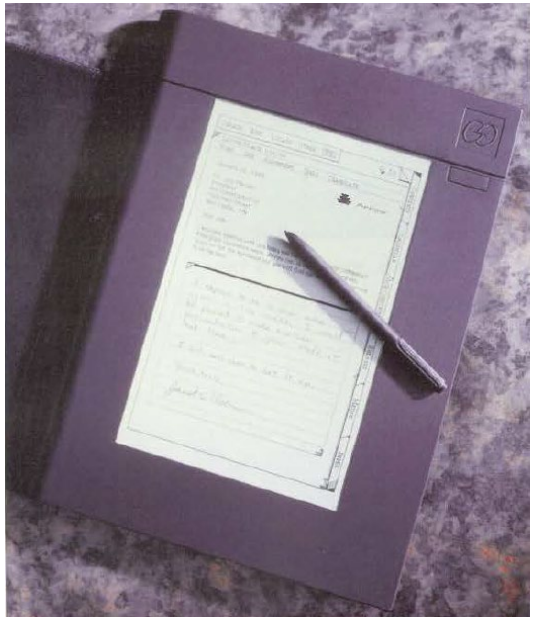


Figure 1: MOVE Command Sequence

Go Corp's "PenPoint" OS

- Founded 1987, released in 1991
- Many gestures for editing, navigation, etc.
  - Flick to scroll and turn pages, circle, insert space, cross-out, insert word, get help, …
  - Press and hold to start moving or selecting
- Special-purpose recognizer for the built-in gestures
- http://research.microsoft.com/en-us/um/people/bibuxton/buxtoncollection/a/pdf/Go%20PenPoint%20Getting%20Started.pdf





Dean Rubine's System

- Dean Rubine at CMU (PhD CSD, 1991) created novel gesture interaction techniques
- Also, a novel "open-source" flexible algorithm, which researchers used for *16 years*.
- Paper: Dean Rubine. 1991. Specifying gestures by example. In *Proceedings of the 18th annual conference on Computer graphics and interactive techniques* (SIGGRAPH '91). ACM, 329-337. http://doi.acm.org/10.1145/122718.122753
- Video: Dean Rubine. 1992. Combining gestures and direct manipulation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '92),* ACM, actual video (10:20) or (ACM Ref for description)

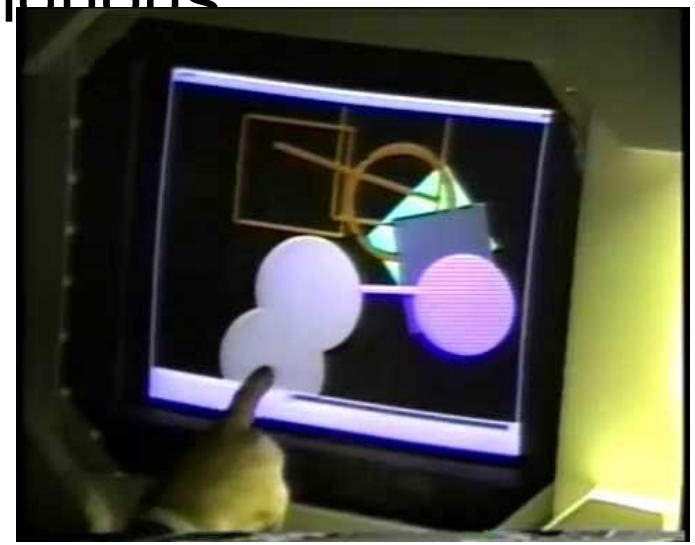
- Powerful and influential system for single-stroke gesture recognition

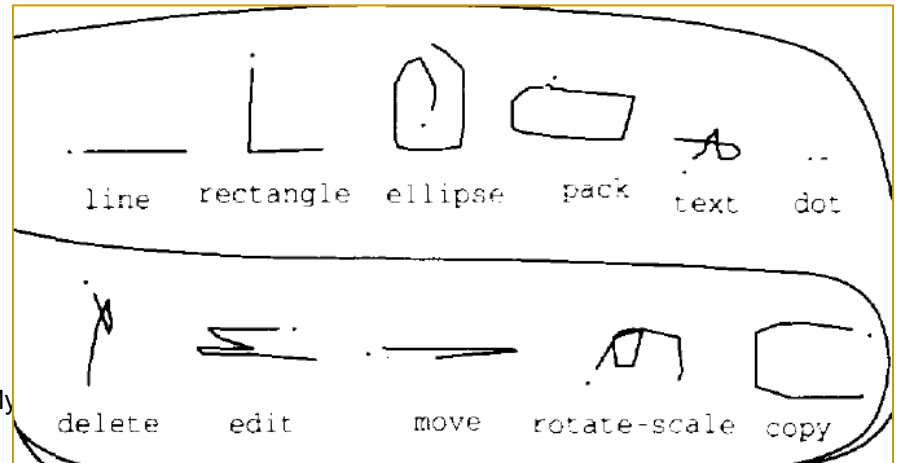
1991

today

Rubine's Gesture Innovations

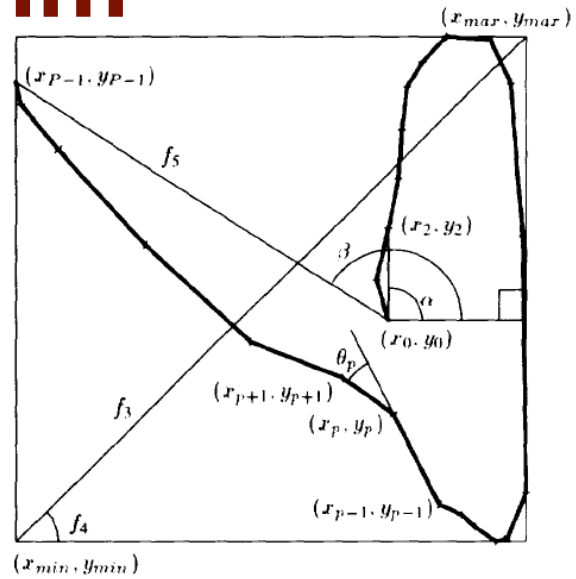
- "Eager recognition" – can recognize a gesture *while mouse button is still down* as soon as it is unambiguous
  - Either wait for mouse pause, or immediately when unambiguous
  - Allows user to continue with direct manipulation
  - E.g., "L" gesture for rectangle, continue to drag for size
  - "C" gesture for copy, "curlicue" for rotate and scale
- Multi-finger gestures also supported
  - Two finger drag and resize
- *local video*, up through 6:00, 7:00-end

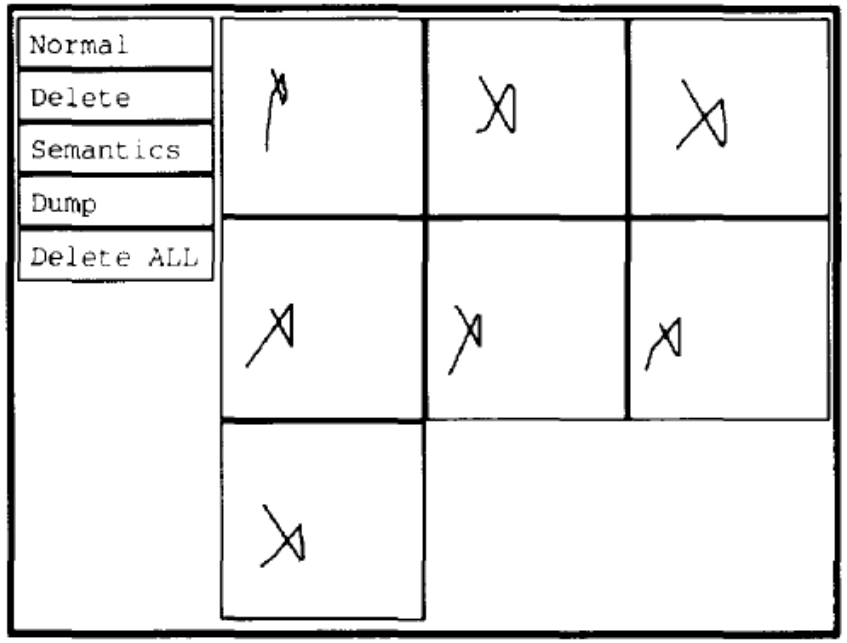




Rubine: Gesture recognition algorithm

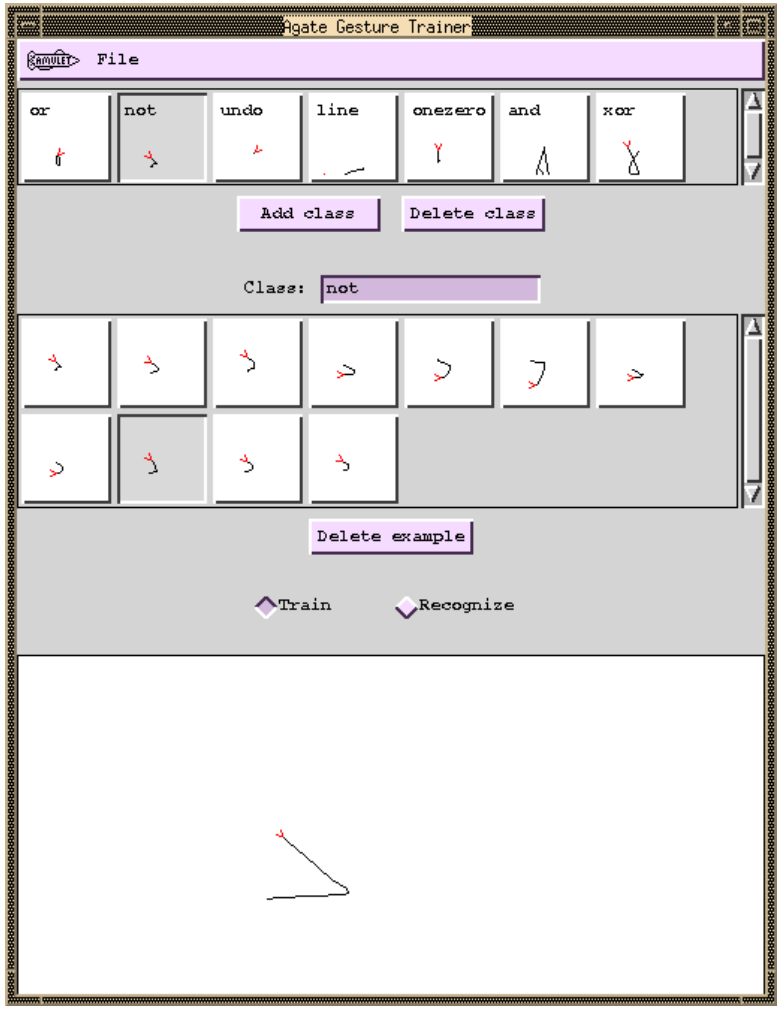
- Trained with a small number of examples (e.g., 15)
  - Since done by a person, won't be identical
  - Examples should vary in whatever ways they will for the user
    - E.g., different sizes? Different orientations?
- Automatically looks for features of all gestures, that differentiates them
  - Uses a Machine Learning algorithm
    - Statistical Single-Stroke Gesture Recognition
    - Computes matrix inversions, discriminant values, and Mahalanobis distances
  - Experimentally picked a set of 13 features that seemed to work well
    - E.g, "cosine and the sine of the initial angle of the gesture, the length and the angle of the bounding box diagonal, …"
- Implemented in a system called GRANDMA
- *local video*, 6:00 through 7:00





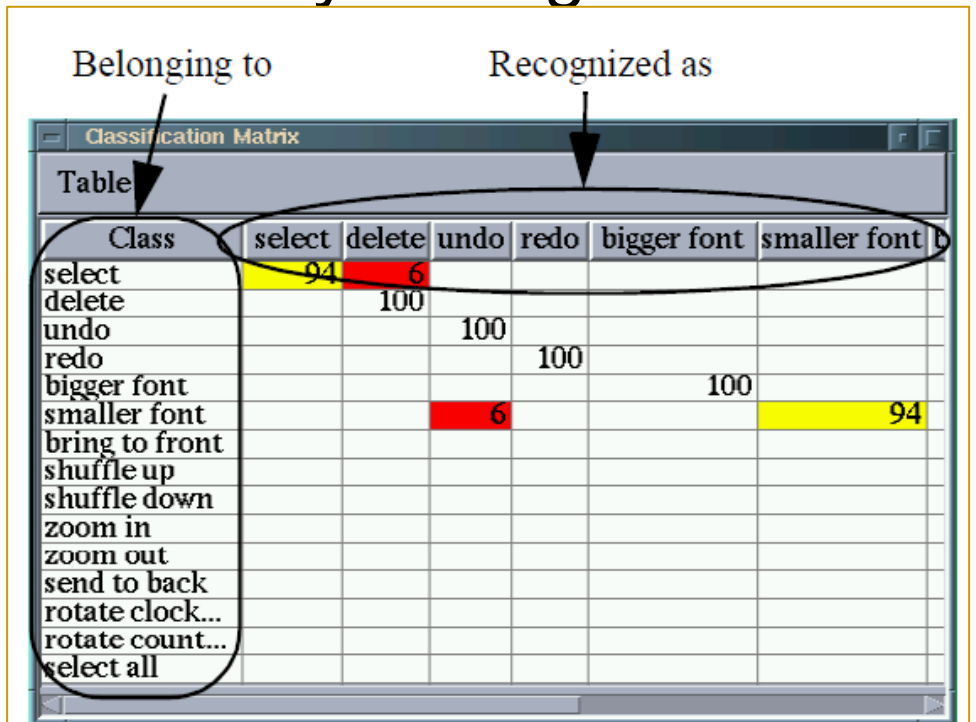
Uses of Rubine's algorithm

- Many subsequent projects re-implemented and built on his algorithm
  - We implemented it twice, both called "AGATE": **A** **G**esture-recognizer **A**nd **T**rainer by **E**xample
  - Integrated with the standard "interactor" event handling model
  - James A. Landay and Brad A. Myers. "Extending an Existing User Interface Toolkit to Support Gesture Recognition," *Adjunct Proceedings of INTERCHI'93*. Amsterdam, The Netherlands, April 24-29, 1993. pp. 91-92. (Garnet)
  - Brad A. Myers, Richard G. McDaniel, Robert C. Miller, Alan Ferrency, Ellen Borison, Andrew Faulring, Andy Mickish, Patrick Doane, and Alex Klimovitski, *The Amulet User Interface Development Environment*. 8 minute video. Technical Video Program of the CHI'1997 conference. ACM, YouTube (local copy) 8:27 total, gestures at 6:00-6:30



Improving the Gestures

- Allan Christian Long Jr., Quill: a gesture design tool for pen-based user interfaces, PhD thesis, UC Berkeley, 2001, (307 pages), pdf
- How to know if the gestures are too similar?
- Chris Long took the Rubine recognizer and analyzes if gestures are too "confusable"
- "Quill" tool
- Similarity in recognition space not necessarily the same as in human perceptual visual space
  - Now would be called "explainable AI"



User Designed Gestures

- Jacob O. Wobbrock, Htet Htet Aung, Brandon Rothrock and Brad A. Myers. "Maximizing the Guessability of Symbolic Input" (Short Talk). *Extended Abstracts CHI'2005: Human Factors in Computing Systems*. Portland, OR, April 2-7, 2005. pp. 1869-1872. pdf. http://doi.acm.org/10.1145/1056808.1057043

- When creating the EdgeWrite gestures, Jake Wobbrock wanted to know what users thought the gestures should be:
  - "Guessability of the EdgeWrite unistroke alphabet was improved by users from 51.0% to 80.1%"
- Multiple phases
  - Participants told the constraints
  - Participants propose a set of gestures – tricky not to bias answers with prompts
  - Get participants to resolve conflicts
    - since likely to create indistinguishable gestures

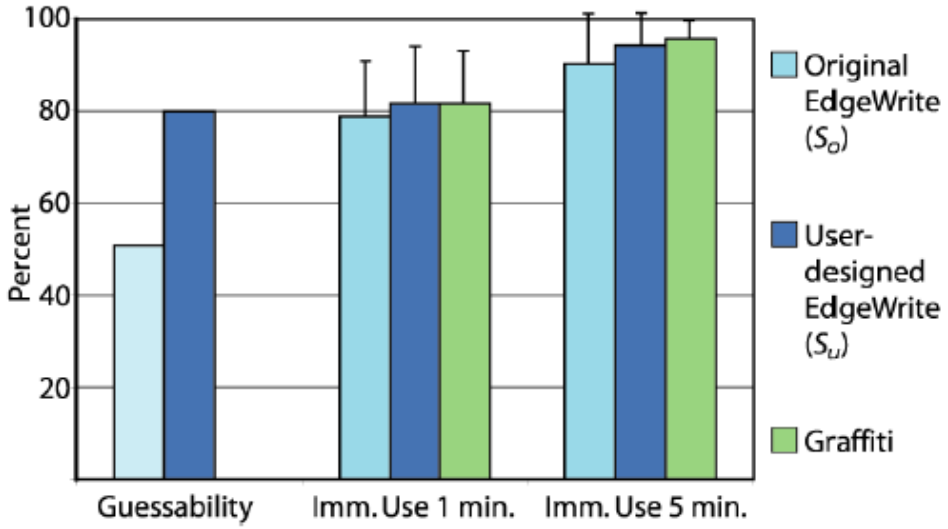
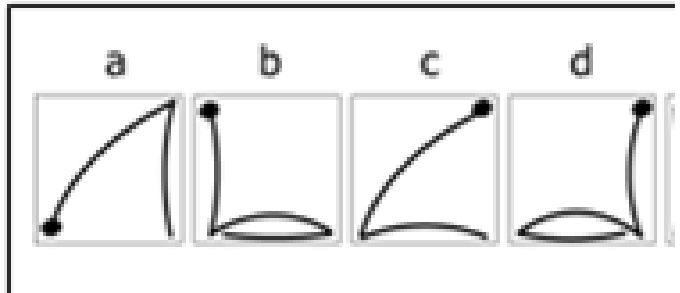


Figure 1. Guessability and immediate usability results. Error bars represent standard deviations. Graffiti data are from [7].



Wobbrock's new recognizers

- Jacob O. Wobbrock, Andrew D. Wilson, and Yang Li. 2007. Gestures without libraries, toolkits or training: a $1 recognizer for user interface prototypes. In *Proceedings of the 20th annual ACM symposium on User interface software and technology* (UIST '07). ACM, pp. 159-168. http://doi.acm.org/10.1145/1294211.1294238 or http://faculty.washington.edu/wobbrock/pubs/uist-07.1.pdf

- More efficient and simpler than Rubine's
- Became the new standard that others use for research
- Unistroke and multi-stroke versions
- Match candidate points to remembered templates
- Default: rotation, size and speed invariant

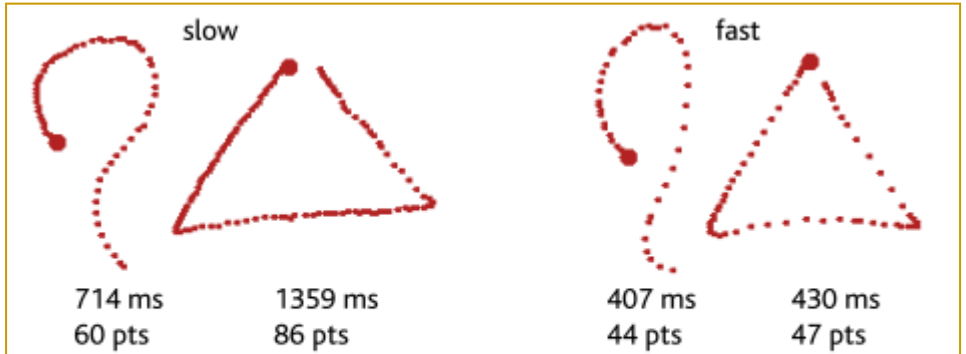


Figure 3. A slow and fast question mark and triangle made by subjects using a stylus on a Pocket PC. Note the considerable time differences and resulting numbers of points.

Design criteria

- Be resilient to variations in sampling due to movement speed or sensing;
- Support optional rotation, scale, and position invariance;
- Require no advanced mathematical techniques (e.g., matrix inversions, derivatives, integrals);
- Be easily written in few lines of code;

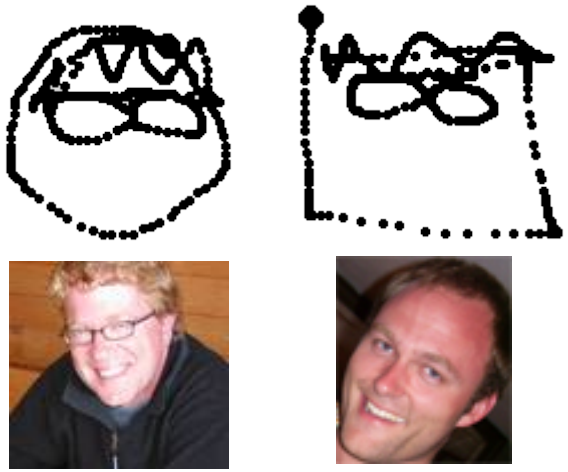
Thanks to Jake Wobbrock for these slides!

Design criteria (cont.)

- Be fast enough for interactive purposes;
- Allow developers and application end-users to “teach” it new gestures with only one example;
- Return an *N*-best list with [0..1] scores that are independent of the number of input points;
- Be conceptually straightforward for easy comprehension, inspection, modification, extension, debugging, etc.

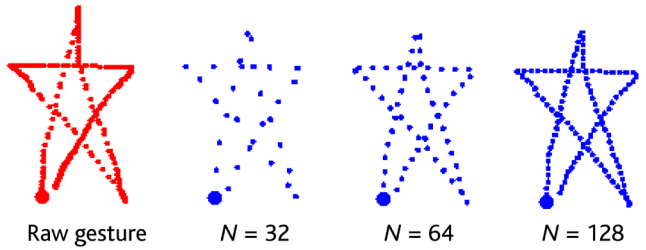
Live demo

- ~100 lines of JavaScript
  - http://depts.washington.edu/acelab/proj/dollar/index.html

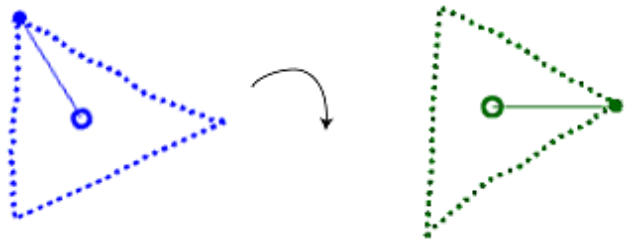


Four easy steps *(on next slides)*

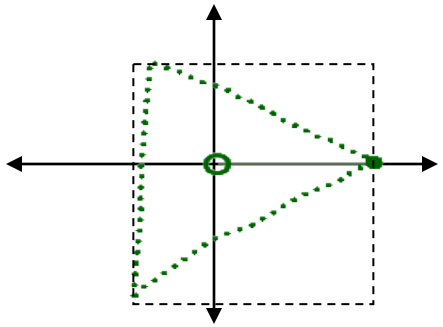
1. Resample



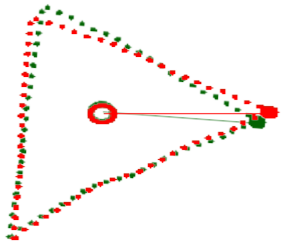
2. Rotate once to 0°



3. Scale, translate

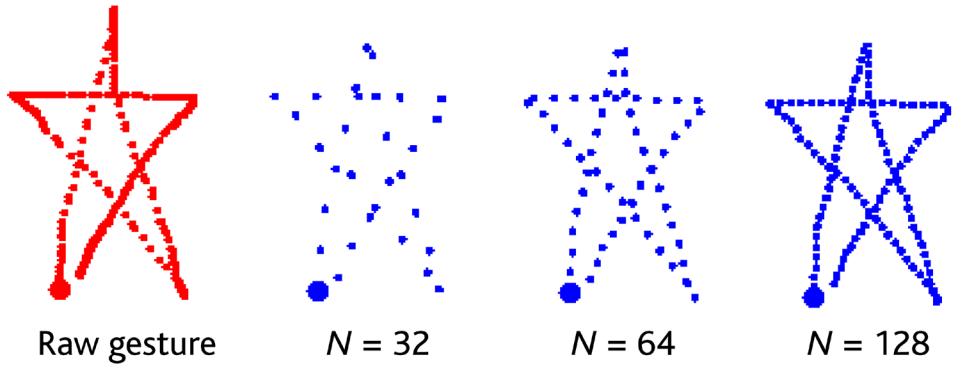


4. Compare to templates



Step 1: Resample

- Resample to *N* equidistant points
  (Plamondon & Srihari 2000,
  Tappert et al. 1990, Kristensson & Zhai 2004)



- Removes clusters and gaps
- Accommodates different sampling rates
- Allows us to compare point $C[k]$ to $T_i[k]$

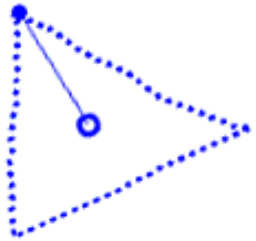
Step 1

Step 1. Resample a *points* path into *n* evenly spaced points.

```
RESAMPLE(points, n)
 1   I ← PATH-LENGTH(points) / (n – 1)
 2   D ← 0
 3   newPoints ← points_0
 4   foreach point p_i for i ≥ 1 in points do
 5       d ← DISTANCE(p_{i-1}, p_i)
 6       if (D + d) ≥ I then
 7           q_x ← p_{i-1_x} + ((I – D) / d) × (p_{i_x} – p_{i-1_x})
 8           q_y ← p_{i-1_y} + ((I – D) / d) × (p_{i_y} – p_{i-1_y})
 9           APPEND(newPoints, q)
10           INSERT(points, i, q)   // q will be the next p_i
11           D ← 0
12       else D ← D + d
13   return newPoints
PATH-LENGTH(A)
 1   d ← 0
 2   for i from 1 to |A| step 1 do
 3       d ← d + DISTANCE(A_{i-1}, A_i)
 4   return d
```

Step 2: Rotate once to 0°

- No closed-form solution for finding best angular alignment
  (Kara & Stahovich 2004)
- Find angle from (x,y) to first point
  - Call it the “indicative angle”
- Rotate this to 0°
- Approximates rotational alignment between C and T_i



Step 2

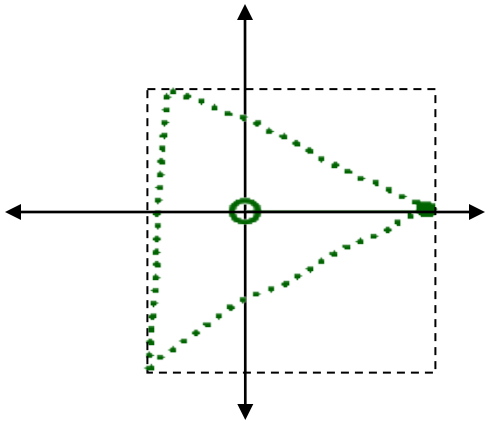
Step 2. Rotate *points* so that their indicative angle is at 0°.

ROTATE-TO-ZERO(*points*)
1 $c \leftarrow$ CENTROID(*points*) // computes $(\bar{x}, \bar{y})$
2 $\theta \leftarrow$ ATAN $(c_y - points_{0_y}, c_x - points_{0_x})$ // for $-\pi \leq \theta \leq \pi$
3 *newPoints* $\leftarrow$ ROTATE-BY(*points*, $-\theta$)
4 **return** *newPoints*

ROTATE-BY(*points*, θ)
1 $c \leftarrow$ CENTROID(*points*)
2 **foreach** point p in *points* **do**
3 $q_x \leftarrow (p_x - c_x)$ COS $\theta - (p_y - c_y)$ SIN $\theta + c_x$
4 $q_y \leftarrow (p_x - c_x)$ SIN $\theta + (p_y - c_y)$ COS $\theta + c_y$
5 APPEND(*newPoints*, q)
6 **return** *newPoints*

Step 3: Scale, translate

- Scale to a square
  - Non-uniform
  - Aspect-invariant
- Translate centroid to origin



Step 3

Step 3. Scale *points* so that the resulting bounding box will be of $size^2$ dimension; then translate *points* to the origin. BOUNDING-BOX returns a rectangle according to (min_x, min_y), (max_x, max_y). For gestures serving as templates, Steps 1-3 should be carried out once on the raw input points. For candidates, Steps 1-4 should be used just after the candidate is articulated.

```
SCALE-TO-SQUARE(points, size)
1   B ← BOUNDING-BOX(points)
2   foreach point p in points do
3       q_x ← p_x × (size / B_width)
4       q_y ← p_y × (size / B_height)
5       APPEND(newPoints, q)
6   return newPoints
TRANSLATE-TO-ORIGIN(points)
1   c ← CENTROID(points)
2   foreach point p in points do
3       q_x ← p_x – c_x
4       q_y ← p_y – c_y
5       APPEND(newPoints, q)
6   return newPoints
```

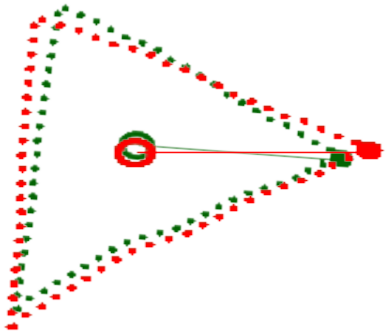
At this point…

- … all templates T_i and any candidate C have been treated identically.

- Now we must compare C to each T_i.
  - To which T_i is C closest?

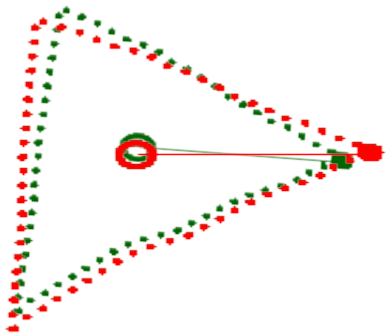
Step 4: Compare to templates

- Compute score [0..1] for each (C, T_i)
  - Score is based on average distance between corresponding points
  - Score should be for *best* angular alignment for (C, T_i)
    - Requires search over angles



"Seed & search"

- Find angle at which avg. point distance is minimized



- Could use brute force
  - +1° for 360°
- Or use hill climbing CW/CCW
  - ±1° for ±180°
  - There can be local minima

Step 4

Step 4. Match *points* against a set of *templates*. The *size* variable on line 7 of RECOGNIZE refers to the *size* passed to SCALE-TO-SQUARE in Step 3. The symbol φ equals ½(-1 + √5). We use θ=±45° and θ_Δ=2° on line 3 of RECOGNIZE. Due to using RESAMPLE, we can assume that A and B in PATH-DISTANCE contain the same number of points, i.e., $|A|=|B|$.

```
RECOGNIZE(points, templates)
1   b ← +∞
2   foreach template T in templates do
3       d ← DISTANCE-AT-BEST-ANGLE(points, T, -θ, θ, θΔ)
4       if d < b then
5           b ← d
6           T′ ← T
7   score ← 1 – b / 0.5√(size² + size²)
8   return ⟨T′, score⟩
```

```
PATH-DISTANCE(A, B)
1   d ← 0
2   for i from 0 to |A| step 1 do
3       d ← d + DISTANCE(Ai, Bi)
4   return d / |A|
```

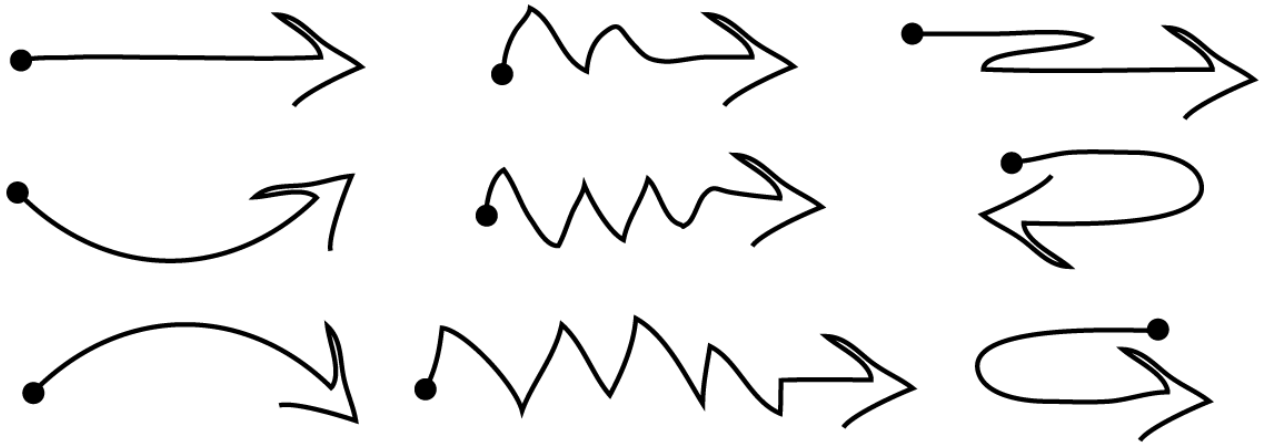
```
DISTANCE-AT-BEST-ANGLE(points, T, θa, θb, θΔ)
1   x1 ← φθa + (1 – φ)θb
2   f1 ← DISTANCE-AT-ANGLE(points, T, x1)
3   x2 ← (1 – φ)θa + φθb
4   f2 ← DISTANCE-AT-ANGLE(points, T, x2)
5   while |θb – θa| > θΔ do
6       if f1 < f2 then
7           θb ← x2
8           x2 ← x1
9           f2 ← f1
10          x1 ← φθa + (1 – φ)θb
11          f1 ← DISTANCE-AT-ANGLE(points, T, x1)
12      else
13          θa ← x1
14          x1 ← x2
15          f1 ← f2
16          x2 ← (1 – φ)θa + φθb
17          f2 ← DISTANCE-AT-ANGLE(points, T, x2)
18  return MIN(f1, f2)
```

```
DISTANCE-AT-ANGLE(points, T, θ)
1   newPoints ← ROTATE-BY(points, θ)
2   d ← PATH-DISTANCE(newPoints, Tpoints)
3   return d
```

Limitations of $1

- Depends on 2-D pairwise point comparisons
  - Resilient to differences in sampling, rotation, scale, position, aspect, and velocity/acceleration
  - But no ovals vs. circles, rectangles vs. squares
    (This can be added on a per-gesture basis)
  - No differentiation based on speed
- 1-D gestures (lines) should not be scaled in 2-D
- No features are used
  - Gesture “classes” require different templates with the same name

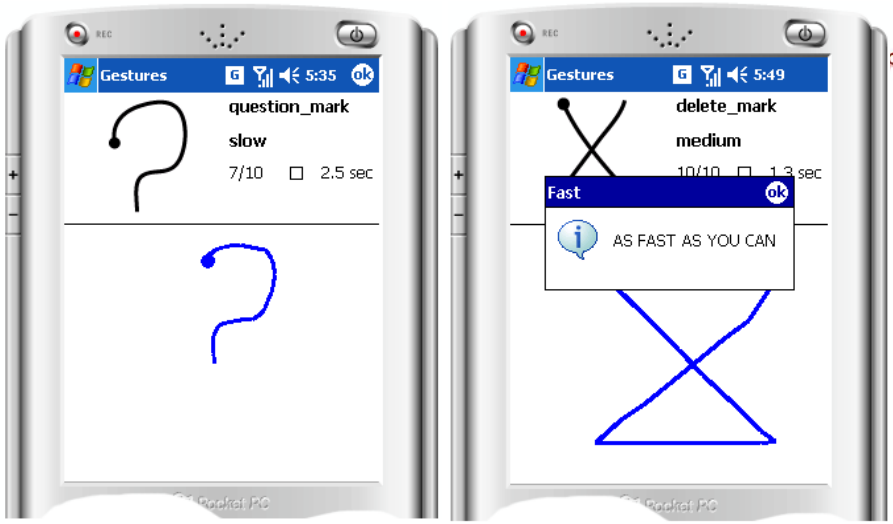
arrow “class”

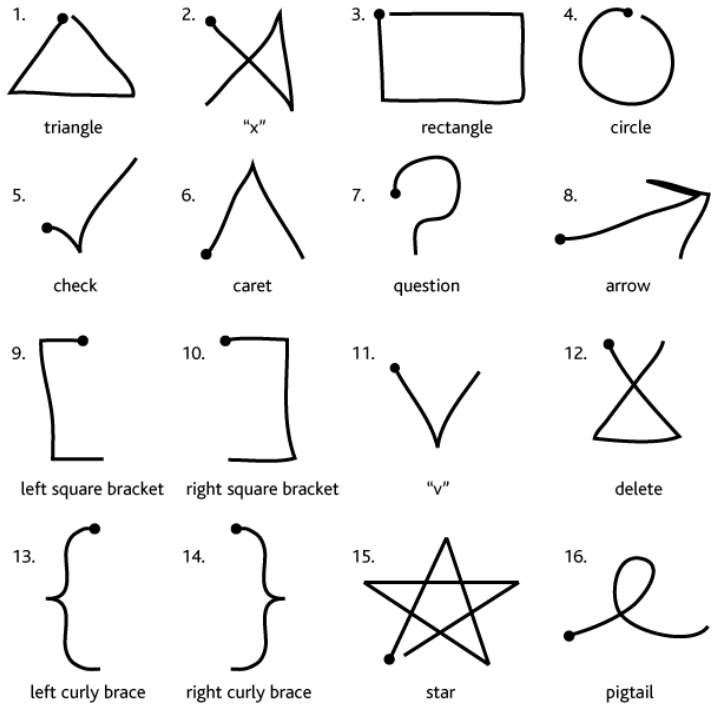


Evaluation

Method

- Tested $1, Rubine, DTW
- 10 subjects
- 16 gestures
  - 10 × (slow, med, fast)
  - 4800 gestures total
  - 1-5 (disliked, liked)
- Train on *E*=1-9, test on one random from 10-*E*. Repeat 100× for error rate.
- 1,248,000 total tests
- 3-factor within-subjects design
  (recognizer, speed, num. train)





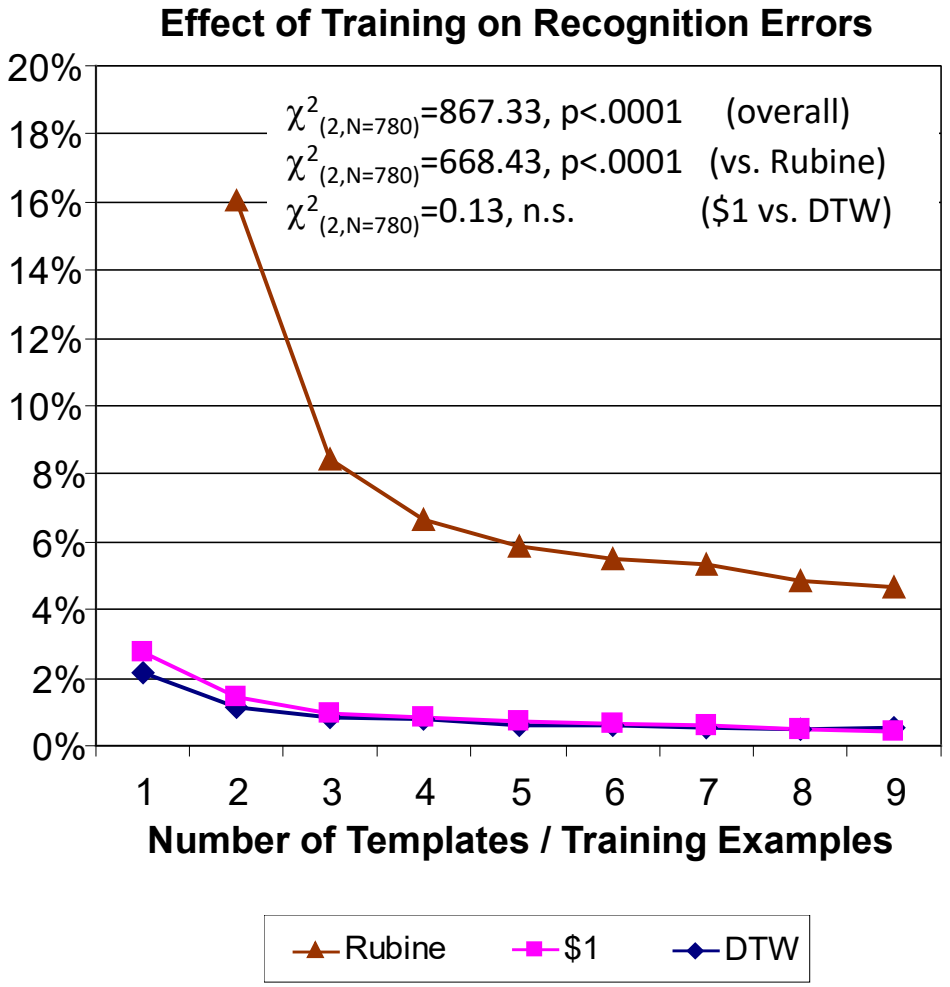
Recognition errors

- $1 0.98% errors
  (1.21% without searching over angles)
- DTW 0.85%
- Rubine 7.17%

- With 1 template:
  - $1: 2.73%
  - DTW: 2.14%
- With 9 templates:
  - $1: 0.45%
  - DTW: 0.54%

- DTW: 80× slower than $1
  - Speedup possible, but complex

- Rubine with 9 train: 4.70%
  - (Rubine reported ~6.5%.)



Wobbrock's subsequent gesture work

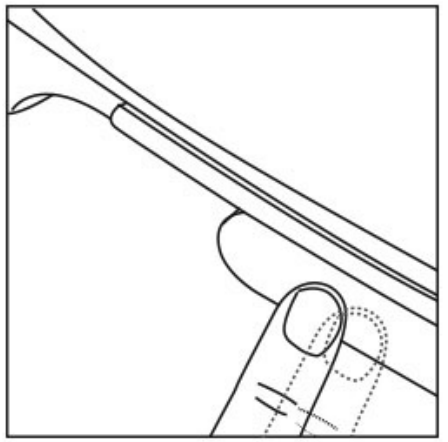
- AGATe: AGreement Analysis Toolkit - for calculating agreement in gesture-elicitation studies (CHI'2015)
- GHoST: Gesture HeatmapS Toolkit - for visualizing variation in gesture articulation (ICMI '2014)
- GREAT: Gesture RElative Accuracy Toolkit - for measuring variation in gesture articulation (ICMI'2013)
- GECKo: GEsture Clustering toolKit - for clustering gestures and calculating agreement (GI '2013)
- $P: Point-cloud multistroke recognizer - for recognizing multistroke gestures as point-clouds (ICMI '2012)
- $N: Multistroke recognizer - for recognizing multistroke gestures as strokes (GI '2012)
- $1: Unistroke recognizer - for recognizing unistroke gestures as strokes (UIST'2007)

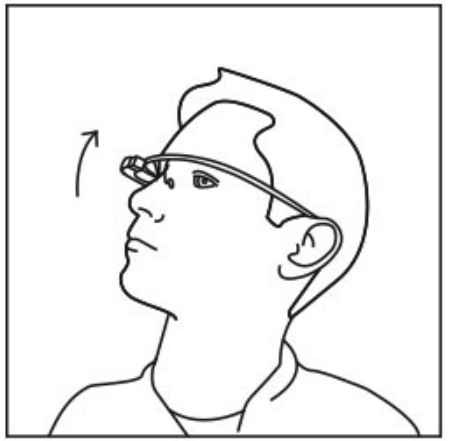
iPhone Gestures

- Quick flick down / up / left / right
  - New behaviors starting in iOS7 in various apps (no affordance)
    - Left and right in Messages, Safari
    - Up and down in home screens
- Swipe down from top
- Swipe up from bottom
- Press and hold (long press)
- Press hard (“3D”) – now abandoned (same as long-press)
- Two finger zoom
  - Also in photo
- Two finger zoom and rotate
  - Google maps
- Undo – shake
- Tilt up – turn on
- Double click and hold = zoom
- Three finger tap – accessibility
- Shake left-right = undo (sometimes)
- …

Google Glass Gestures

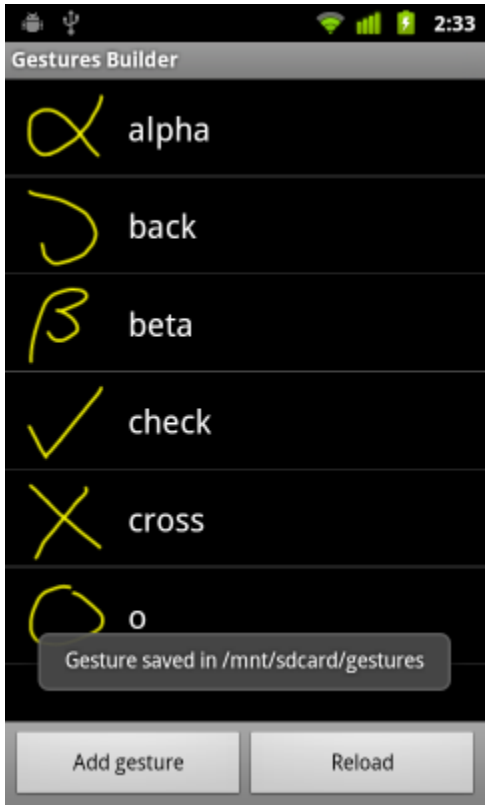
- https://support.google.com/glass/answer/3064184?hl=en
- Small touch pad on right side & Motion sensor
- **Activate Glass:** Tap the touchpad to turn the display on
- **Swipe forward and back:** affect content being shown
- **Select an item:** Tap
- **Tilt head up / down**: display on / off





Android Gesture Builder

- All Smartphones have libraries to support programming apps with gestures
  - Often provided to the code by “events” like “mouse-down” → “swipe-left”
- Android provides nice tool to define gestures by example
  - http://developer.android.com/training/gestures/index.html
  - http://android-coding.blogspot.com/2011/09/gestures-builder-create-your-gestures.html
  - http://android-developers.blogspot.com/2009/10/gestures-on-android-16.html



Funny

- Tyson R. Henry, Scott E. Hudson, Andrey K. Yeatts, Brad A. Myers, and Steven Feiner. "**A Nose Gesture Interface Device: Extending Virtual Realities**," *ACM Symposium on User Interface Software and Technology*, Hilton Head, SC, Nov. 11-13, 1991. pp. 65-68. ACM DL or local copy and slides.

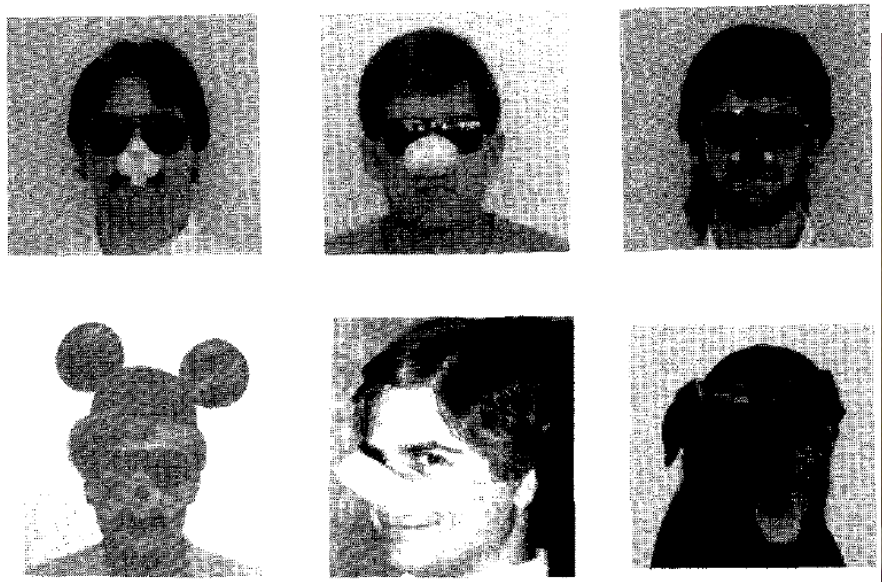


Figure 1: Alternative Noses: Bunny, Pig, Elephant, Mouse, Duck, Dog

More References

- From Bill Buxton, www.billbuxton.com
- The first gesture-related stuff that I did was the single-stroke shorthand that I developed for entering music to the score editor. This was the stepping stone to Unistrokes and that to Grafitti.
  - **Buxton, W., Sniderman, R., Reeves, W., Patel, S. & Baecker, R. (1979)**. The Evolution of the SSSP Score Editing Tools. *Computer Music Journal* 3(4), 14-25. [PDF] [video]
- The paper that you referred to as well as the accompanying video can be found here;
  - **Buxton, W., Fiume, E., Hill, R., Lee, A. & Woo, C. (1983).** Continuous Hand-Gesture Driven Input. *Proceedings of Graphics Interface '83,* 9th Conference of the Canadian Man-Computer Communications Society, Edmonton, May 1983, 191-195. [video]
- For a review of Marking and Gesture stuff, see the following two draft chapters of the yet-to-be-finished (!) input book:
  - http://www.billbuxton.com/inputManuscript.html
  - Marking Interfaces
  - Gesture Driven Input
- IMHO, the most useful thing that I have written that guides me, at least, in terms of gestures, is:
  - **Buxton, W. (1986).** Chunking and Phrasing and the Design of Human-Computer Dialogues, *Proceedings of the IFIP World Computer Congress*, Dublin, Ireland, 475-480.
- **The two things that I always discuss when I speak about gestures are:**
  - **Kreuger's work & introduction of the pinch gesture, etc.:** http://www.youtube.com/watch?v=d4DUIeXSEpk
  - **Richard Bolt's work combining gesture and speech:** http://www.youtube.com/watch?v=RyBEUyEtxQo
- **There is also some nice examples from Lincoln Lab:**
  - Applicon (circa 1970). An interactive trainable computer aided circuit design system using hand-drawn shapes to enter data and commands. Applicon. 16 mm film. 2:25 min excerpt
    - The quick story is this – Applicon was a spin-off from Lincoln Labs, and the recognition stuff was born there. Fontaine Richardson, who was behind the work, was a key person at the lab. There was little published on this stuff, but it was the offspring of Sketchpad, and – I believe – the first commercial system to use these types of gestures – or gestures at all.
  - http://www.billbuxton.com/Lincoln.html
  - http://www.billbuxton.com/LincolnLab.pdf
- **An old summary which still has some relevance:**
  - **Buxton, W. (1995).** Touch, Gesture & Marking. Chapter 7 in R.M. Baecker, J. Grudin, W. Buxton and S. Greenberg, S. (Eds.)(1995). Readings in Human Computer Interaction: Toward the Year 2000 San Francisco: Morgan Kaufmann Publishers.